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SOLID-STATE TRIP CIRCUIT BREAKERS IN NAVY ELECTRICAL POWER SYSTEMS

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the physical behavior of the circuit breakers. The effect of temperature on the time-versus-current characteristics was negligible; the characteristics were still within the manufacturers' specified tolerance for this temperature range. The results of these temperature tests indicate that the solid-state curcuit breakers are superior to the molded-case circuit breakers for installation where high ambient temperatures prevail or where coordination of protective devices is important. The salt-fog tests showed that the electronic trip units are more vulnerable to failure in a heavy salt-laden environment than the trip units of electromechanical circuit breakers.

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The Civil Engineering Laboratory was tasked by the Naval Facilities Engineering Command to investigate the suitability of solid-state trip circuit breakers as substitutes for electromechanical circuit breakers Navy electrical power systems. Two types of tests were conducted. ambient temperature was varied to determine its effect on the time-versus-current curve, and a salt-fog environment was simulated to determine its effect on the physical behavior of the circuit breakers. The effect of temperature on the time-versus-current characteristics was negligible. the characteristics were still within the manufacturers' specified tolerance for this temperature range. The results of these temperature tests indicate that the solid-state circuit breakers are superior to the molded-case circuit breakers for installation where high ambient temperatures prevail or where coordination to protective devices is important. The salt-fog tests showed that the electronic trip units are more vulnerable to failure in heavy salt-laden environment than the trip units of electromechanical circuit breakers.

INTRODUCTION

Various contractors have recently offered circuit breakers with solid-state trips for installation in Navy electrical power systems at the same or slightly higher cost than their electromechanical counterparts. No data have been available on the suitability of solid-state circuit breakers as replacements for electromechanical breakers, especially under adverse environmental conditions.

The objective of this investigation was to evaluate the time-versus-current characteristics of the solid-state trip circuit breaker over the temperature range of 25°C to 70°C and after exposure to a salt-fog environment. The results of this investigation were compared to the results of a previous evaluation* of electromechanical circuit breakers under identical environmental conditions.

BACKGROUND

The primary purpose of over-current protection is to save the electrical insulation of the power system from excessive heat. This heat is generated by the current in the conductor and is equal to the square of the current times the resistance. The electrical insulation is rated to withstand temperatures up to a particular value. The temperature that the insulation will be exposed to will be a function of the energy put in to the wire (I^2R) and the ambient temperature.

It would be possible to protect the insulation by providing a device that would interrupt any current that exceeded the rating of the wire regardless of its duration. This system would be acceptable if all of the electrical loads were resistive. The electrical power distribution system is composed of a large number of transformers with a large part of the loads being motors. These components require from three to ten times as much current to start as they do when operating at full load. The duration of the starting currents is short, and the temperature of the insulation does not increase fast enough to reach its limit.

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* Naval Civil Engineering Laboratory. Technical Note N-1309: Evaluation of Low Voltage Switchgear for Ship-to-Shore Power, by K. W. Lucci. Port Hueneme, California, Nov 1973.

For an over-current protective device to handle starting loads and still protect conductor insulation from abnormal conditions, it must interrupt the excess current if it exists for a prescribed time duration. This can be accomplished by: the thermal action of bi-metal in electromechanical molded-case circuit breakers; the dashpot of power circuit breakers; an electromagnetic induction motor in protective relays; or an electronic solid-state circuit in the solid-state trip circuit breaker.

The electromechanical molded-case circuit breaker has time-versus-current characteristics similar to that of Figure 1. The long-time characteristics are produced by the thermal action of bi-metal and are, therefore, sensitive to changes in ambient temperature and residual heat from previous over-current conditions. A change in the ambient temperature will also affect the maximum amount of continuous current the breaker will allow to pass without operating. Figure 2 shows the effect of ambient temperature on a typical molded-case circuit breaker.

The solid-state trip circuit breakers use an electronic sensing circuit to produce the long-time characteristics. Figure 3 shows the time-versus-current curve for a typical solid-state circuit breaker. The long-time characteristics are given by the term $I^k t$, where k is approximately 2. Manufacturers of circuit breakers make no statement about how temperature affects the time-versus-current curve.

To reduce the large electromagnetic forces generated by a fault, an additional magnetic trip circuit can be added to the protective device. This circuit interrupts any current in excess of the pre-set value as rapidly as is mechanically possible. The magnetic trip circuit is essentially the same as the molded-case circuit breaker, solid-state trip circuit breaker, power circuit breaker, and protective relays. The time-versus-current curves for all of these devices are similar in this region.

TEST BREAKERS

The following solid-state trip circuit breakers were selected for laboratory test and evaluation. All of these breakers are Underwriter Listed.

- Westinghouse, type MC3800F, solid-state trip molded-case circuit breaker, three-pole, 600-VAC, 800-ampere frame with 400-ampere rating electronics

- Westinghouse, type SPCE-600, solid-state trip system circuit breaker, three-pole, 600-VAC, 600-ampere frame with 400-ampere trip unit.

- General Electric, type TJS-3604, solid-state trip insulated-case circuit breaker, three-pole, 600-VAC, 600-ampere frame with 400-ampere trip unit.

- Allis Chalmers, type LA-600, power circuit breaker with solid-state trip, three-pole, 600-VAC, 600-ampere frame with 400-ampere solid-state trip unit.

TEST EQUIPMENT

The following test equipment were utilized to simulate current and environmental conditions:

- Multi-Amp, model CB-150, circuit breaker test unit

Power rating	:	15 KVA
Input	:	208/220/480 volts, 60 Hz
Output	:	Adjustable 60-Hz current output over the following ranges 0 to 3-volt range: 5,000 amp max 0 to 6-volt range: 2,500 amp max 0 to 12-volt range: 1,200 amp max
Elapsed time	:	Timer capable of measuring the elapsed time of the test from 0.01 second to 1 hour
Current accuracy	:	Current output meter with accuracy of ±2% of full scale

Associated Jade, model Mx-9216, salt spray chamber

Construction material	:	Lucite
Insulation	:	Double wall design
Temperature control	:	Thermostat at 35°C for chamber Thermostat at 49°C for salt spray

TEST PROGRAM

Time-Versus-Current Tests

The selected circuit breakers were tested with the Multi-Amp Corporation's CB-150 circuit breaker test unit. Currents of 400, 500, 700, 900, 1,200, 1,500, 1,800, 2,100, 2,400, 2,800, and 3200 amperes were simulated with this test unit. The circuit breakers were placed in an oven to control the temperature of the breakers.

The time required for the test circuit breaker to trip at each of the above current levels was recorded. The first time-versus-current data were taken at a 16°C ambient temperature. To determine the effects of temperature on the circuit breaker, the temperature in the oven was raised to 55°C. After the test breaker had been exposed to this temperature for over 3 hours, the time to trip the breaker for each of the simulated current levels was recorded. The temperature in the oven was then raised to 70°C, and the same procedure was followed.

Additional temperatures were considered; however, the effect of temperature on the time-versus-current was so slight that the breakers were still in the tolerance of the published data at 70°C.

Salt-Fog Tests

This test procedure was intended to accelerate the effect of salt spray on the circuit breakers; the procedure is in accordance with Method 509 of MIL-STD-810B.

The test items were placed in the salt spray chamber. A solution of 95% distilled water and 5% salt was used to generate a salt-fog. The test items were exposed to this salt-fog at a temperature of 35°C for 96 hours. The test items were allowed to dry for 48 hours, and the time-versus-current characteristics were checked. This procedure was repeated four times.

MIL-STD-810B states that the salt-fog test does not truly duplicate the effects of marine atmosphere, and that a direct relationship between the salt-fog test and actual coastal conditions does not exist. The intent of this test was to point out weaknesses in the unit that are subject to failure when exposed to a marine atmosphere.

TEST RESULTS

Time-Versus-Current

The solid-state trip circuit breakers tested were found to be rapidly resetable and relatively insensitive to temperature. Their time-versus-current curves were repeatable and within manufacturers specifications over the temperature range of 16°C to 70°C.

The molded-case circuit breaker uses the thermal action of bi-metal to trip the breaker when an over-current condition occurs. The temperature of the bi-metal acts as a memory of previous over-current conditions.

The solid-state trip circuit breakers do not retain a memory of previous currents for a long time. The solid-state trip circuit breaker may, therefore, be reclosed immediately after an over-current condition has opened the circuit breaker. The time to trip the breaker after reclosure will be that of the time-versus-current curve.

It is possible that insulation, of a conductor protected by a solid-state trip circuit breaker, could be damaged due to overheating if the breaker were rapidly and repeatedly reclosed whenever the current exceeded the current-carrying capacity of the conductor.

The effects of temperature on the time-versus-current curves of the circuit breakers tested are shown in Figures 4 through 7. The major effect was a shift of less than 15%, with respect to current, of the long-time curve as the temperature was raised from 16°C to 70°C. There was less than a 2.5% shift in the minimum current that will trip the circuit breakers over the same temperature range.

The results of similar testing on molded-case circuit breakers indicated a 20% shift, with respect to current, of both the long time curve and the minimum current that will trip the circuit breaker as the temperature is raised from 40°C to 70°C.

Salt-Fog

The results of the salt-fog test showed the solid-state trip circuit breaker electronics to be more vulnerable to a heavy salt-fog environment than the molded-case circuit breaker. The mechanical portion of the solid-state trip circuit breakers is essentially the same as the molded-case circuit breaker and subject to the same failures. The electronic failures were the result of salt deposits shorting out the wiring in potentiometers, in transformers, or between electronic components.

The General Electric circuit breaker failed after 4 weeks of exposure to the salt-fog. The failure of the electronic portion was due to corrosion of the current transformers. The time of exposure before failure was the same as for molded-case circuit breakers, and the major failures were in the mechanical portion of the breaker.

The electronic trip units of the remaining circuit breakers tested failed after 2 weeks in the salt-fog environment.

No direct relationship exists between the time for the circuit breaker to fail under the salt-fog test conditions and the life expectancy of the circuit breaker when installed in an electrical power system. The intent of this test was to point out potential weaknesses in the circuit breakers when exposed to marine atmospheres.

CONCLUSIONS

1. The manufacturer gives a tolerance of approximately ±10% of the current required to trip the solid-state circuit in a given time. This tolerance is not a function of temperature as is the case with molded-case breakers.

2. The solid-state trip circuit breakers were within the manufacturers' specified tolerance over the temperature range of 16°C to 70°C.

3. The time required to trip the solid-state trip circuit breaker at a given current is repeatable. This is true even if the breaker has just been reset after a trip.

4. The solid-state trip circuit breaker can be reset immediately after tripping due to over-current.

5. The electronics portion of the solid-state trip circuit breaker are more susceptible to failure due to exposure to salt-laden environments than the mechanical portion of the breaker.

RECOMMENDATIONS

1. The solid-state trip circuit breaker should be installed instead of electromechanical circuit breakers in locations where ambient temperatures surrounding the breaker may vary widely.

2. The solid-state circuit breaker is recommended for installations where coordination of protective devices is important.

3. The solid-state trip circuit breaker may be installed in salt-laden environments providing the breakers are mounted in suitable weather-tight enclosures.

4. To prevent overheating of cable insulation due to repeated reclosures on an overload condition the breaker installation should have a warning sign. This sign should require investigation of the cause of the tripping after the third successive trip operation.

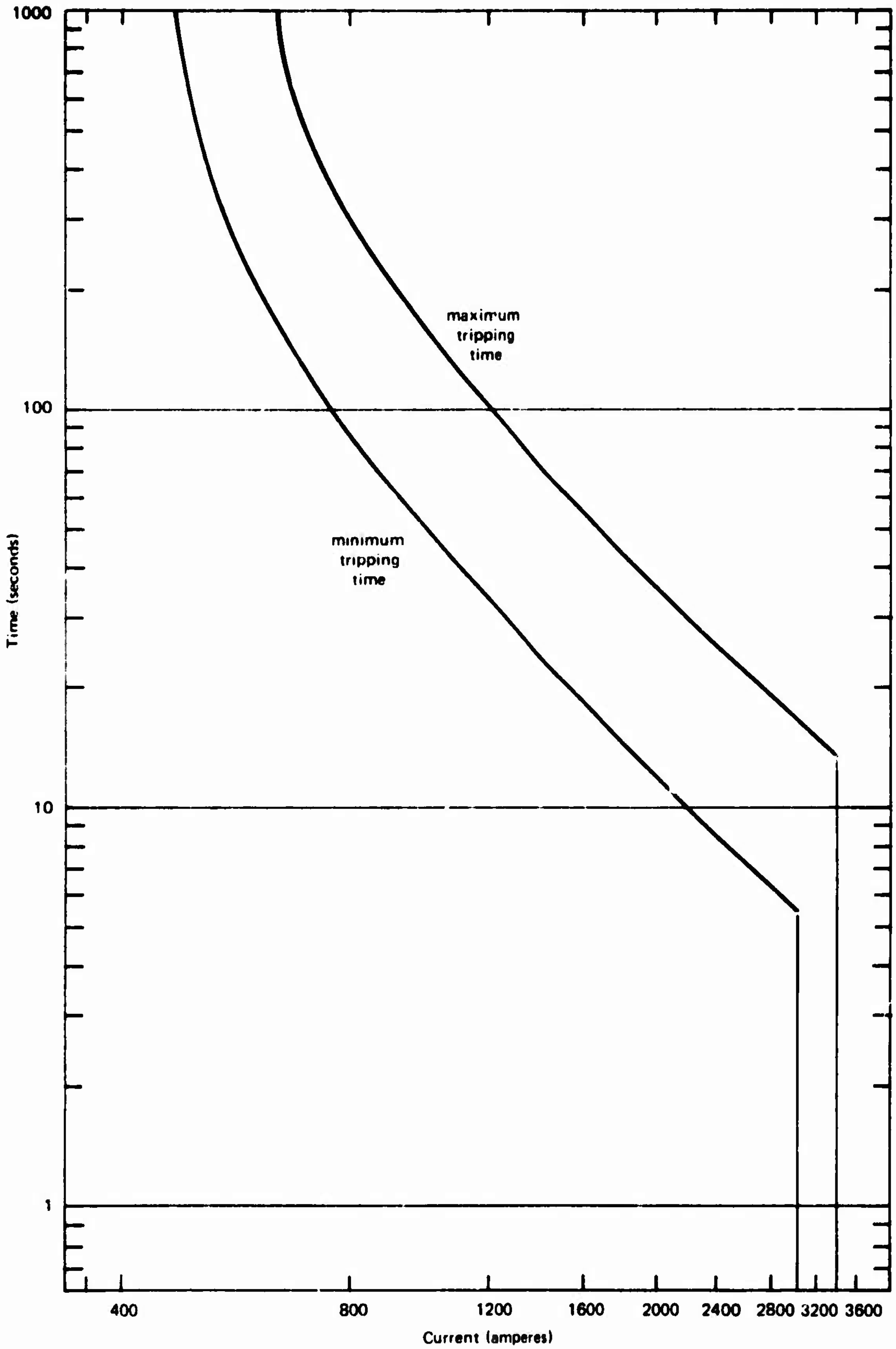

Figure 1. Typical time-versus-current characteristics for an electromechanical molded-case circuit breaker.

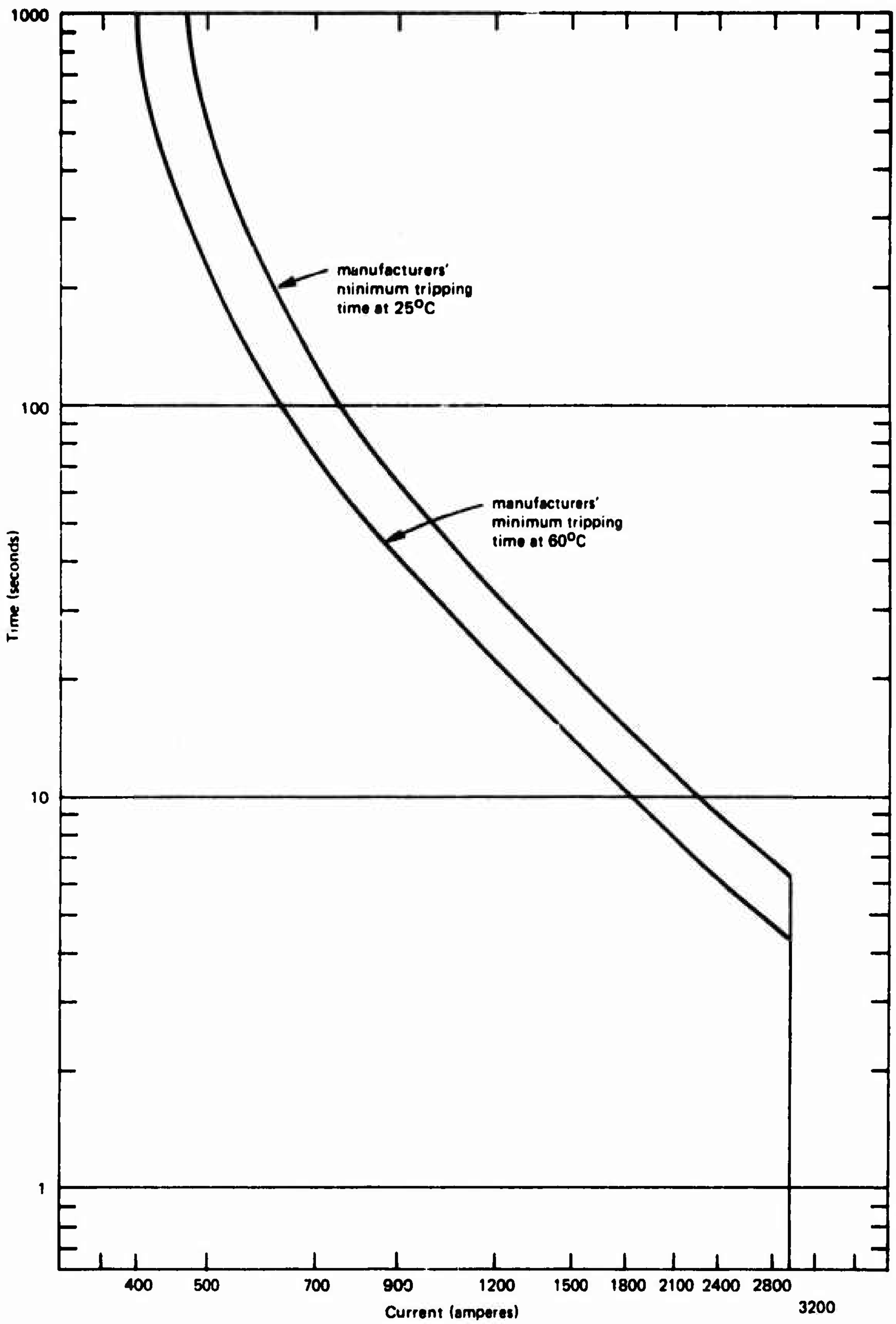

Figure 2. Effect of ambient temperature on a typical molded-case circuit breaker.

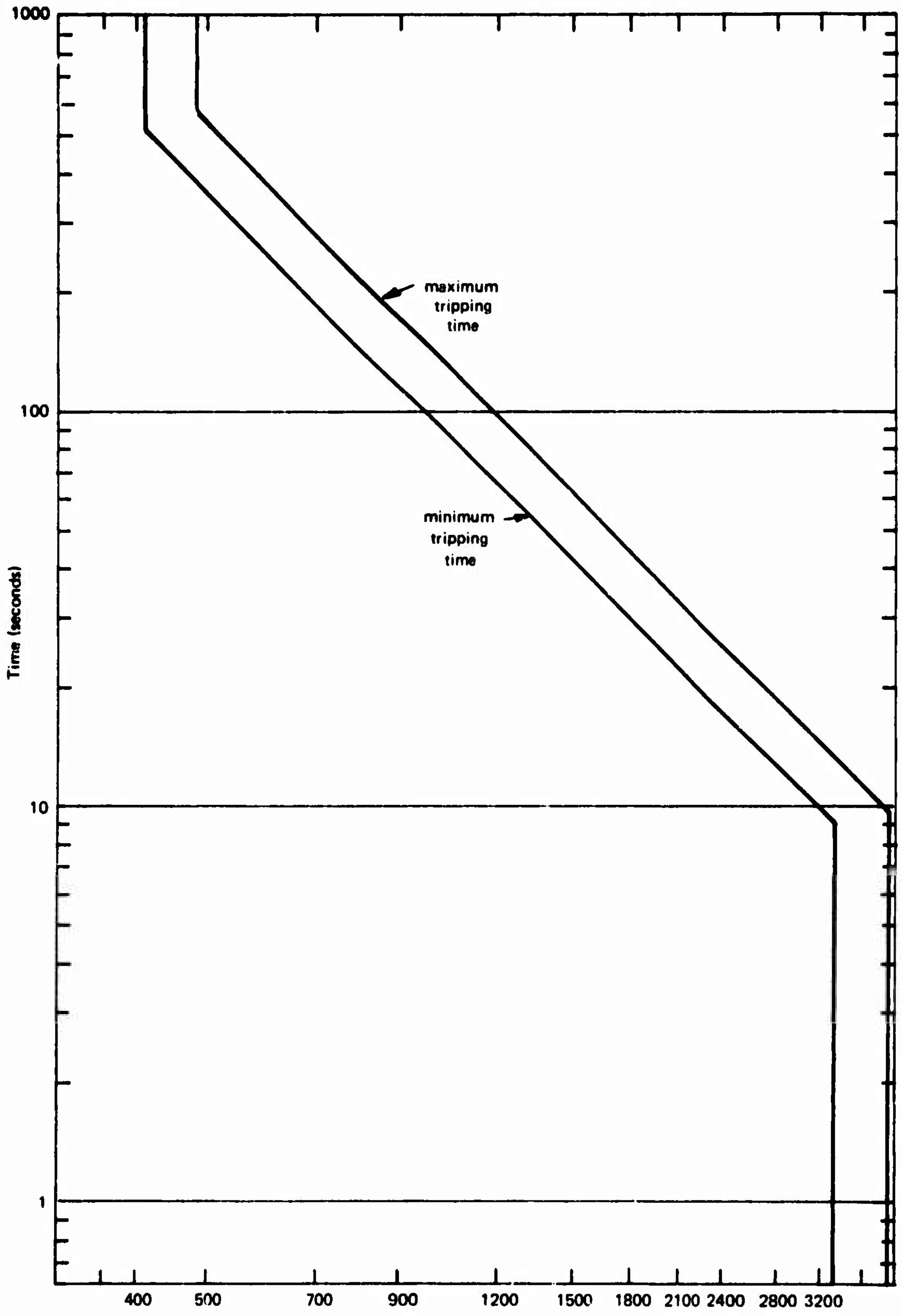

Figure 3. Typical time-versus-current curve for a solid-state circuit breaker.

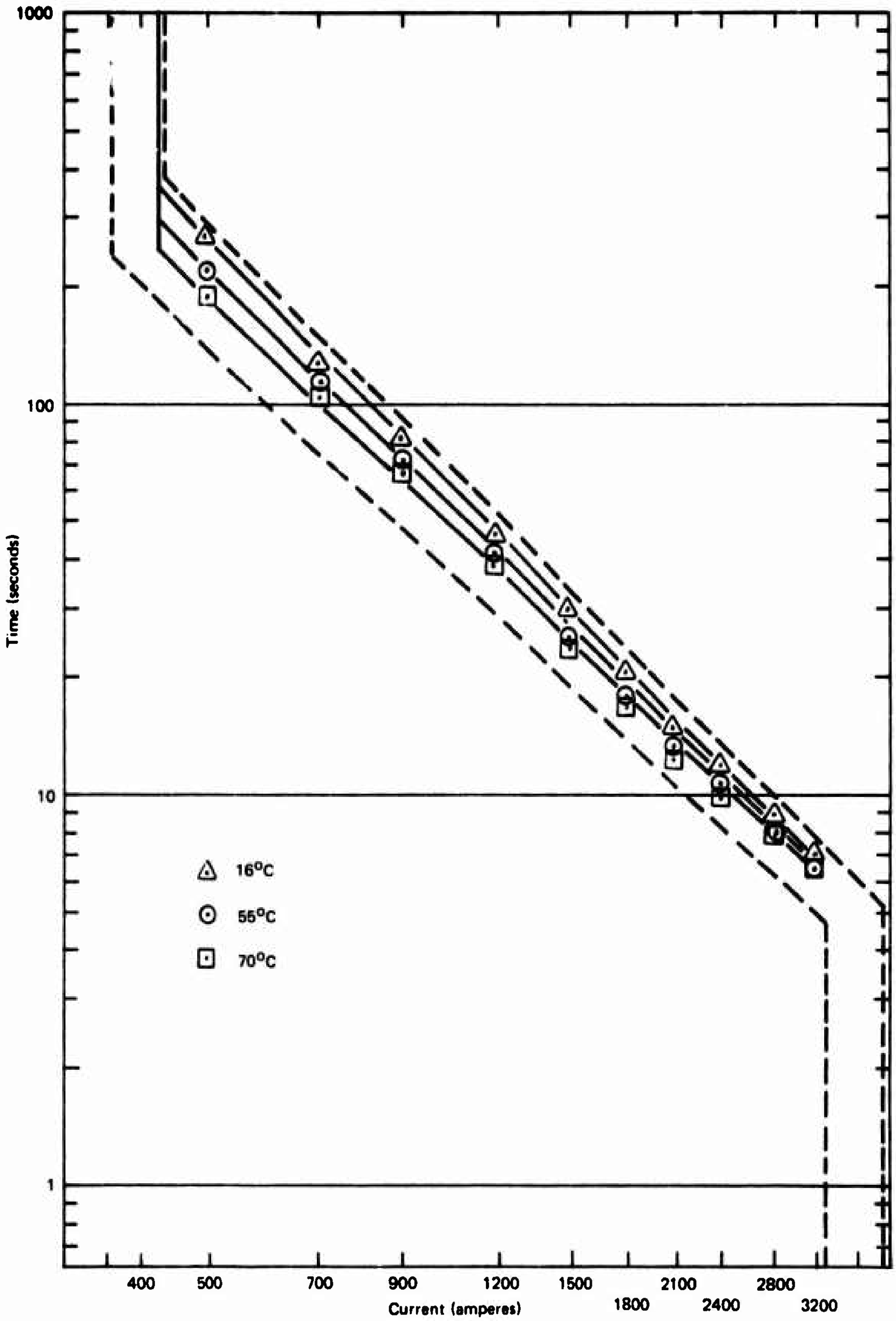

Figure 4. Effect of temperature on the time-versus-current curve for the Westinghouse type MC3800F solid-state circuit breaker.

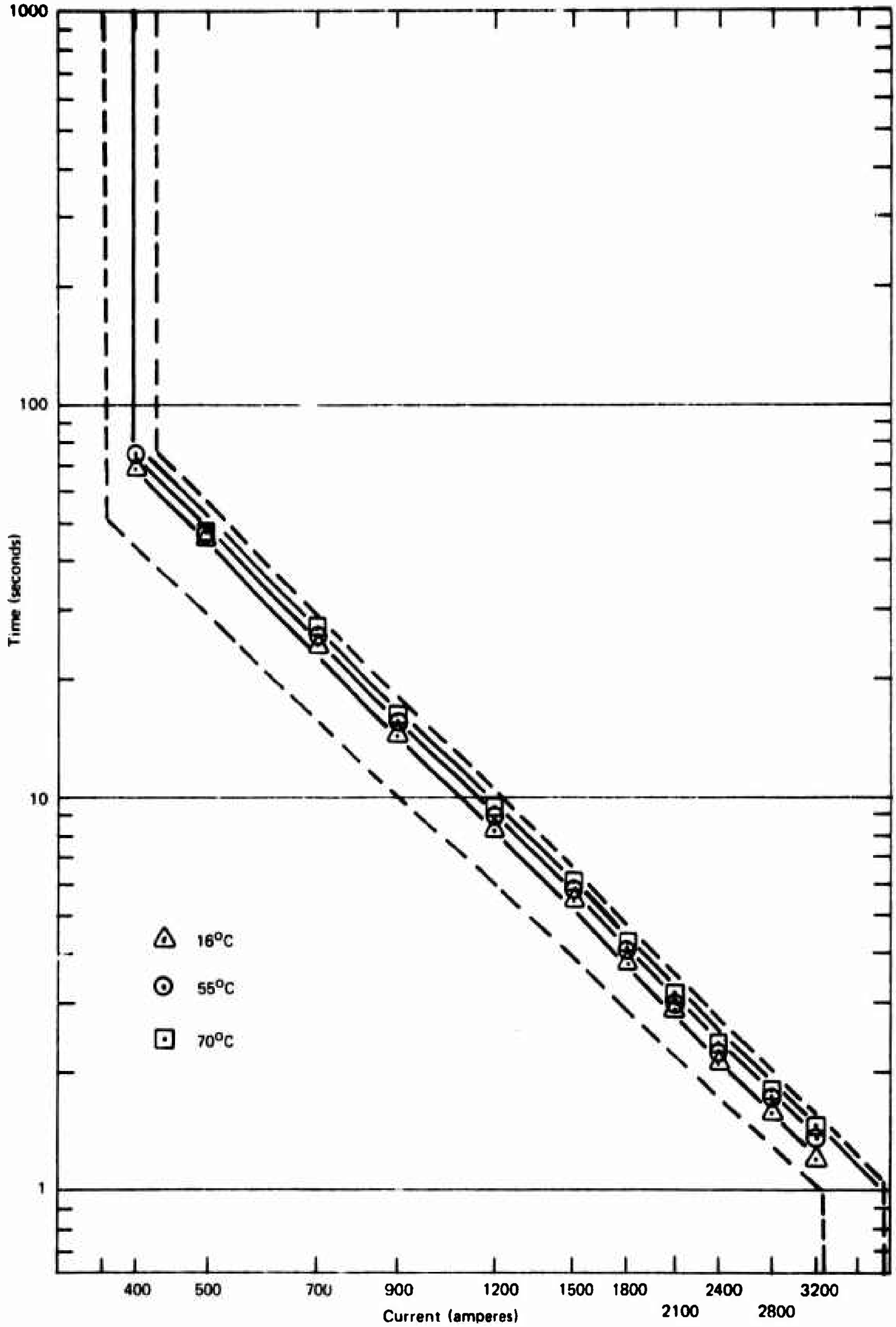

Figure 5. Effect of temperature on the time-versus-current curve for the Westinghouse type SPCE-600 solid-state circuit breaker.

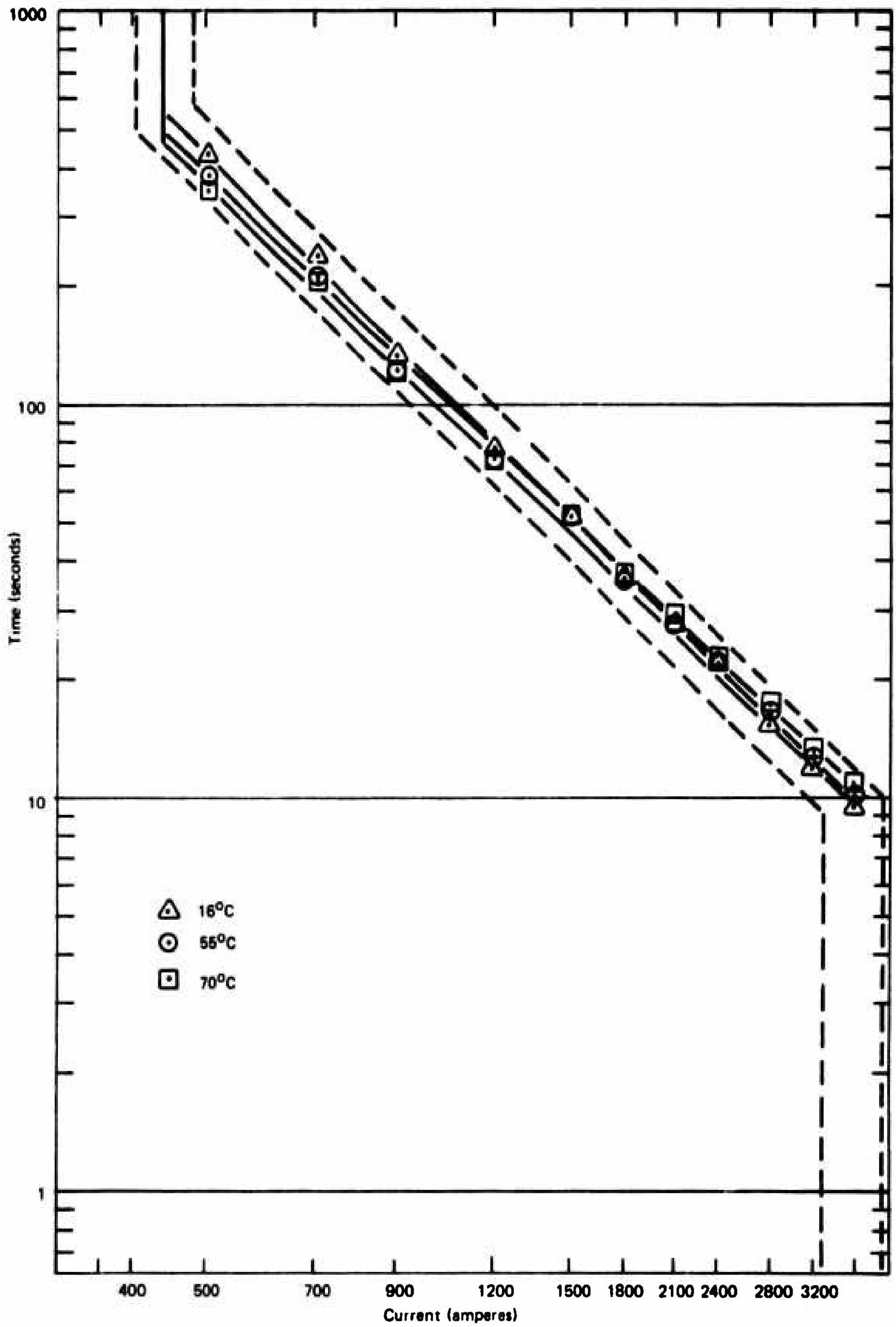

Figure 6. Effect of temperature on the time-versus-current curve for the General Electric type TJS-3604 solid-state circuit breaker.

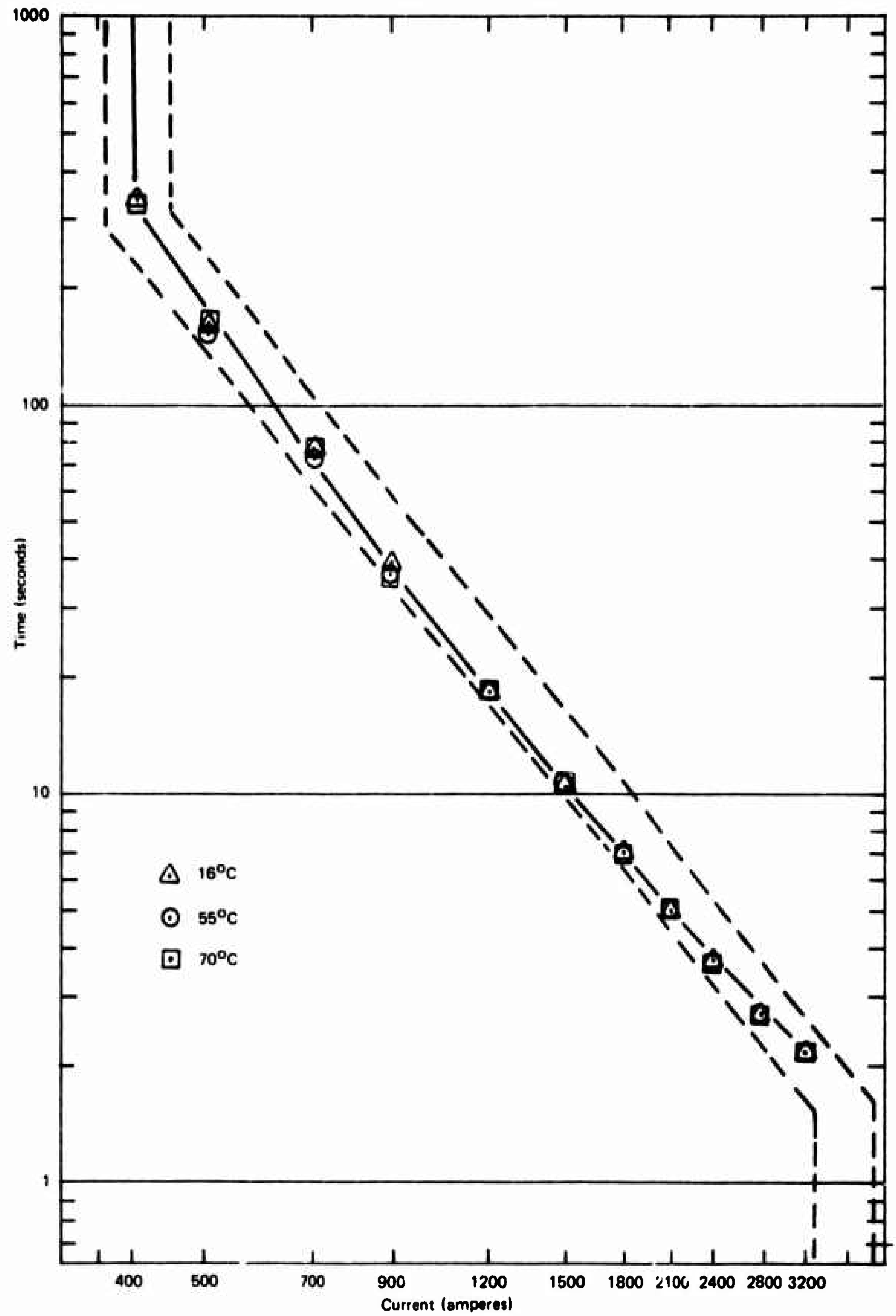

Figure 7. Effect of temperature on the time-versus-current curve for the Allis-Chalmers type LA-600 solid-state circuit breaker.